

Jet Areas, and What They are Good For ^a

MATTEO CACCIARI

LPTHE

Université P. et M. Curie - Paris 6, Université D. Diderot - Paris 7 and CNRS, Paris, France



We introduce the concept of the area of a jet, and show how it can be used to perform the subtraction of even a large amount of diffuse noise from hard jets.

1 Introduction

Jet clustering algorithms, which map the particles observed in the final state of a high-energy collisions into a smaller number of (usually) well defined objects – the jets – are widely used in the study of the properties of strong interactions. The jets are usually meant to be good proxies of the original partons (though the detailed relation is more subtle), and by studying them one tries to probe the underlying dynamics. The reason for using the jets, rather than directly the observed hadrons, is that they can be construed as infrared-safe observables: they are therefore amenable to perturbative QCD predictions, and their sensitivity to non-perturbative phenomena (hadronisation, underlying event and pileup effects) can either be kept under control or corrected for.

In this talk we explore the issue of the susceptibility of jets to contamination from soft radiation distributed in the form of a roughly uniform and diffuse background. Physical examples are the pileup originated by multiple minimum bias collisions in high-luminosity hadron colliders like the LHC, the many particles produced in a central heavy ion collision and, to a lesser extent, the underlying event given by perturbative and non-perturbative QCD radiation whenever strongly-interacting particles are produced at high energy. We shall argue that this susceptibility can be quantitatively characterised in terms of the novel concept of *area of a jet*, which we shall rigorously introduce. In turn, this will suggest a procedure by means of which such contamination can be subtracted from the jet momentum, so as to recover – to a large extent – its proxy relation with the parton it originated from.

^aIn collaboration with Gavin Salam and Gregory Soyez. Presented at Moriond QCD, La Thuile, Italy, March 2007. To appear in the Proceedings.

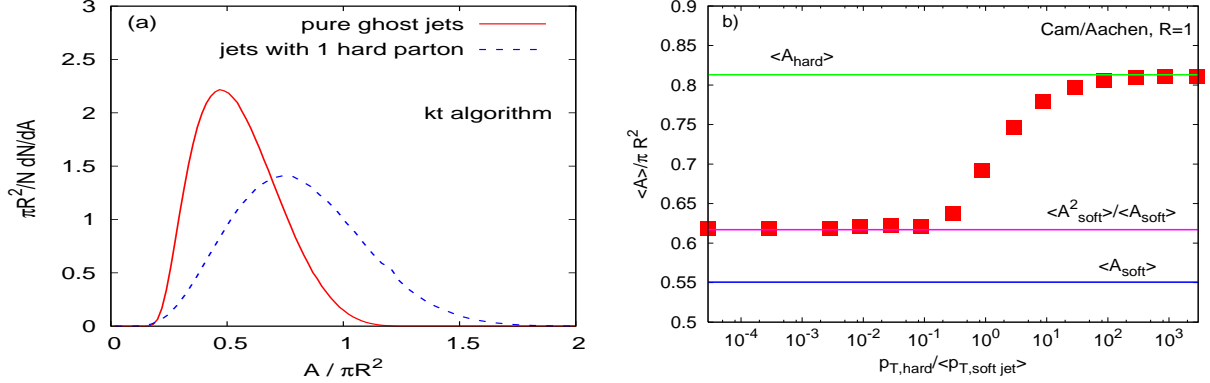


Figure 1: a) Active area distributions for the k_t algorithm³. Cambridge/Aachen⁴ has a very similar behaviour. b) Average are of jet containing a hard particle as a function of the ratio of its momentum to that of the soft background jets.

Naively, one can think of the jet area as the surface (in the rapidity-azimuth plane) over which the particles that have been clustered into a given jet are distributed. One can also assume that the amount of diffuse background radiation clustered together with the jet will be proportional to this area. One could therefore think of determining somehow the momentum surface density of this noise, ρ , and successively subtract from the jet momentum a quantity given by ρ times the area of the jet.

Before such a program can be implemented in practice, however, the jet area needs to be defined more rigorously, and a procedure to extract ρ must be devised. This is done in¹ and² respectively, where both aspects are introduced and extensively studied.

2 Jet Area

The naive vision of the jet area as the surface covered by the particles that make up the jet quickly turns out to be fallacious: as the particles are point-like, this area is zero. Drawing some sort of boundary, like for instance a convex hull – the minimal set of particles such that all the others are contained in the polygon drawn through them – is also prone to ambiguities: different jets may overlap, and a region of space might be arbitrarily assigned to a jet irrespectively of the properties of the clustering algorithm.

To overcome these difficulties, we propose a definition of jet area which is inherently related to the clustering procedure, and which can properly account for the jet contamination due to a diffuse background. Our definition is strictly dependent on the infrared-safety property that a good jet algorithm should have: the addition of one (or many) soft particles to the event should not change the final set of hard jets. We add therefore a large number of uniformly distributed and extremely soft particles (*ghosts*) to the event, and cluster them together with the real particles. At the end of the clustering procedure, the number of ghosts clustered with each jet will provide a robust measure of the jet's extension in the rapidity-azimuth plane, and define therefore its *active area*, A .^b

Fig. 1(a) shows how the values for this active area are distributed for two kinds of events: on one extreme, jets constituted of many uniformly distributed particles with similar momenta (the pure-ghost jets); on the other extreme, a jet containing a single hard particle. We can see that these two situations produce different distributions for the active areas, with different averages:

^bThe drawback of this procedure is that a very large number of particles needs to be clustered (a few thousands ghosts are needed to achieve accuracies of the order of one per cent). This would be unfeasible – or at least extremely unpractical – without the fast implementations of the k_t ³ and the Cambridge/Aachen⁴ jet algorithms provided by **FastJet**⁵. This package also provides the tools to calculate the area of the jets, as well as an interface to the new infrared-safe cone algorithm SIScone⁶.

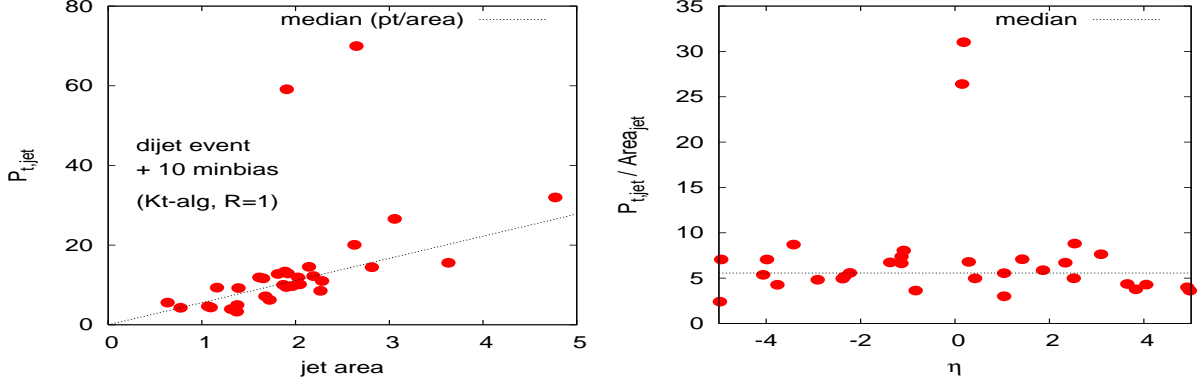


Figure 2: A dijet event superimposed to 10 minimum bias events originated by moderate-luminosity pileup in pp collisions at the LHC, as simulated by PYTHIA.

the jets containing many similar particles have a typical area of order $\langle A^{soft} \rangle \simeq 0.55 \pi R^2$ (R is the typical radius parameter present in most jet algorithms), while the jets containing a single hard particle tend to be larger, their average area being $\langle A^{hard} \rangle \simeq 0.81 \pi R^2$.

One can take farther this exploration of similarities and differences between soft (i.e. uniform) and hard jets, and explore how the transition takes place: fig. 1(b) shows the average area of the jet containing the single “hard” particle as its transverse momentum p_t changes from being negligible with respect to the soft background to being much larger. One can see that in the $p_{t,hard} \gg \langle p_{t,soft\ jet} \rangle$ limit the $\simeq 0.81 \pi R^2$ value for the average area is recovered. On the other hand, in the opposite $p_{t,hard} \ll \langle p_{t,soft\ jet} \rangle$ limit the “hard” jet now behaves like a soft one, the difference in average area being only of probabilistic nature related to the “measurement” of the area of the specific jet containing a given particle.

3 Noise Level

The estimation of ρ , the typical level of the background radiation, could probably be performed in many ways. The method we propose here is related to the jet areas discussed above. It relies on the observation that the transverse momentum of a jet divided by its area, p_{ti}/A_i , behaves differently for the hard jets and for the background ones. Typically, the jets originating from the background radiation cluster themselves in a band, while the hard jets stick out. This is clearly shown in fig. 2. This event is a simulated pp collision at the LHC at moderate luminosity: 10 additional minimum bias events are added to the main hard collision, which produces a dijet event with jets of transverse momentum of the order of 50 GeV. Fig. 2 (left) shows that the areas of the various jets can fluctuate widely. However, when the same jets are plotted in terms of p_{ti}/A_i (right plot) one clearly see the band established by the background. Different strategies can be devised to quantitatively determine its level. One of the simplest one is to take the *median* of all the p_{ti}/A_i , an operation that prevents the few hard jets from biasing its value. We define therefore:

$$\rho = \text{median} \left[\left\{ \frac{p_{ti}}{A_i} \right\} \right]. \quad (1)$$

In the specific case of the event of fig. 2, the momentum density of the background is therefore $\rho \simeq 6$ GeV per unit area.

4 Background Subtraction

Once the area of each jet, A_i , and the noise level ρ are known, one can correct the transverse momentum via the following operation:

$$p_{ti}^{(\text{sub})} = p_{ti} - \rho A_i. \quad (2)$$

We show how this works in practice by considering the following toy model: we generate many events which contain a single hard particle, with a transverse momentum $p_t^{hard} = 100$ GeV, embedded in a background of 10000 soft particles, each with an average transverse momentum $\langle p_t^{soft} \rangle = 1$ GeV (with little fluctuations, 10%, around this value) and randomly uniformly distributed in rapidity and azimuth up to $y_{max} = 4$. In this particular case we can of course calculate the transverse momentum density (per unit area) of the soft particles from the input parameters, since we know how we generated them:

$$\rho = \left\langle \frac{dp_t^{soft}}{dy d\phi} \right\rangle = \frac{10000 \times 1 \text{ GeV}}{2 \times y_{max} \times 2\pi} \simeq 200 \text{ GeV} . \quad (3)$$

This situation might look extreme, but similar values are expected in realistic cases, like a central Pb Pb collision at the LHC.

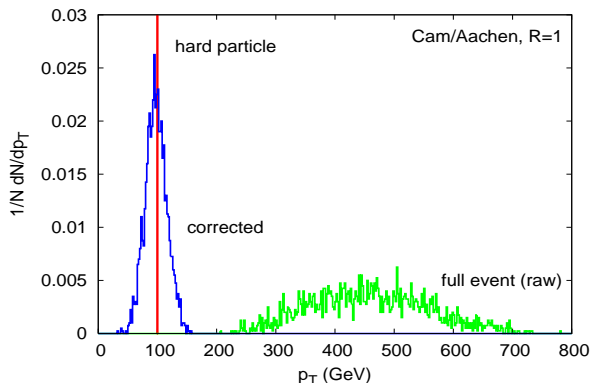


Figure 3: Jets containing a hard particle with $p_{t,hard} = 100$ GeV clustered together with a soft background (green, “raw” histogram), and after its subtraction (blue “corrected” one). The ‘4-vector’ versions of the area and of the subtraction^{1,2}, more appropriate for large R , have been used for this plot.

fig. 3: the transverse momentum of the hard jet is displaced, by an amount consistent with our estimate, and the resolution is hopelessly bad (green histogram, “raw”). However, once the subtraction is performed according to eq. (2) (using for each event the ρ directly extracted from the clustering, as explained in Sec. 3, and *not* the fixed value of eq. (3), of course), the correct average transverse momentum is recovered, together with a large fraction of the resolution (blue histogram, “corrected”).

This toy model shows the feasibility and the accuracy of the determination of the noise level and of the subtraction procedure. More realistic examples, and references to experimental investigations of the problem of background subtraction, are given in².

Acknowledgements. This work has been performed, and is partially in progress, with Gavin Salam and Gregory Soyez, whom I thank for an extremely stimulating collaboration.

References

1. M. Cacciari, G.P. Salam and G. Soyez, LPTHE-07-02, in preparation
2. M. Cacciari and G.P. Salam, LPTHE-07-01, in preparation
3. S. Catani, Y. L. Dokshitzer, M. H. Seymour and B. R. Webber, Nucl. Phys. B **406** (1993) 187 and refs. therein; S. D. Ellis and D. E. Soper, Phys. Rev. D **48** (1993) 3160 [hep-ph/9305266].
4. Y. L. Dokshitzer, G. D. Leder, S. Moretti and B. R. Webber, JHEP **9708**, 001 (1997) [hep-ph/9707323]; M. Wobisch and T. Wengler, hep-ph/9907280.
5. M. Cacciari and G. P. Salam, Phys. Lett. B **641** (2006) 57 [arXiv:hep-ph/0512210].
6. G. P. Salam and G. Soyez, JHEP **0705** (2007) 086 [arXiv:0704.0292 [hep-ph]]